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RAPID X-RAY VARIABILITY IN EINSTEIN OBSERVATIONS OF K AND M DWARFS

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Quiescent variability (at a significance level of $\gtrsim$99%) was detected in 15 of 16 late type stars observed by the Einstein IPC. The program stars (see Table 1) ranged in spectral type from G6 III + F9 III (Capella) to dM8e (CN Leo). Only reprocessed data (Revision 1) were used. Each observation was screened for instrumental artifacts, including the proximity of the Sun-lit Earth to the field of view, which could simulate flux variability. A full description appears in Ambruster, Sciortino and Golub (1985).

The analysis utilized the statistical routine of Collura et al. (1985), which was developed to detect nonperiodic variability, its characteristic timescale, and amplitude, in low flux sources. One of the main features of this routine is the calculation of a phase-averaged $\chi^2$ for each time bin, in order to minimize random statistical fluctuations. Variability is detected if the average $\chi^2$ at any bin size exceeds the chosen significance levels, here 10%, 1.0%, and 0.1% probability that the source is constant.

Some of the most important observational results of the survey are:

1) Quiescent coronal variability is ubiquitous among dKe and dMe stars (see Table 1);

2) The characteristic timescales for 14 of the 15 variable stars are longer than the longest statistically useful time bin, i.e., a few hundred to ~$10^3$ s. The characteristic timescale for 40 Eri C is ≈150 s, as shown by the break in slope, or decrease in significance level, when the bin size exceeds the characteristic timescale;

3) The amplitude of variability (generally $\gtrsim$20%) appears to be independent of spectral type between dK5 (EQ Vir) and ~dM5 (EQ Peg, AD Leo);

4) Significant variablity is found even for very late, supposedly fully convective M dwarfs (L789-6, CN Leo, Prox Cen, UV Cet). There is even a suggestion that the variability amplitude actually increases for the coolest stars: the variability amplitude for L789-6, CN Leo and Prox Cen is ~40%, about twice that of earlier stars;

5) Some stars, e.g., EQ Vir and L789-6 (Gl.866), showed variability in one IPC observation but no significant variability in another.

Recently a correlation between quiescent $L_x$ and time averaged optical (U-band) flaring luminosity has been found for M dwarfs (Doyle and Butler 1985; Skumanich

Table 1. Program Stars.

| Star | Spectral type | Log $L_x$ (ergs $s^{-1}$) | Total integration Time ($10^3$ s) (Number of observations) | Variability code[a] |
|---|---|---|---|---|
| UV Cet | dM5.5e | 27.5 | 19.0 (4) | C, V, VV |
| 40 Eri C | dM4e | 28.3 | 3.8 (1) | V |
| Ross 614 | dM5e | 26.9 | 3.8 (1) | V |
| YY Gem | dM1e | 29.6 | 2.1 (1) | C |
| YZ CMi | dM4.5e | 28.5 | 23.0 (4) | C, V, VV |
| AD Leo | dM3.5e | 29.0 | 18.4 (1) | V, VV |
| CN Leo | dM6.5e | 27.1 | 3.1 (2) | C, V |
| EQ Vir | dK5e | 29.4 | 16.4 (2) | C, V, VV |
| Prox Cen | dM5e | 27.2 | 8.7 (1) | VV |
| CR Dra | dM1e | 29.1 | 7.2 (1) | V: |
| W630 | dM3.5e | 29.3 | 2.2 (1) | V |
| BY Dra | dM0e | 29.5 | 7.5 (1) | C: |
| AU Mic | dM0e | 29.9 | 1.4 (1) | V |
| L789-6 | dM5.5e | 26.9 | 3.6 (2) | C, VV |
| EQ Peg | dM4e | 28.8 | 4.0 (1) | V |
| Capella | G6 III + F9 III | 30.3 | 2.3 (1) | V |

[a]C = constant; V = variable at 99.0-99.9% level; VV = variable at $\geq$ 99.9% level.

1985; Whitehouse 1985). This has prompted suggestions that stellar coronae may be heated by the integrated energy from very low energy flares, the so-called microflares (Skumanich 1985; Haisch 1985). An actual detection of "microflares" has been claimed from EXOSAT observations of UV Cet (Butler and Rodono 1985). Initially, it may seem tempting to attribute the variability we see in the Einstein data in terms of such microflares, however, a few cautionary comments are in order.

The term microflares derives in much of the current discussion from the solar hard X-ray (~20 keV) microflares (mean energy ~$10^{24}$ ergs $s^{-1}$) detected in a balloon flight by Lin et al. 1984. However, events with $L_x \sim 10^{-3}$ that of the quiescent corona are at present undetectable on stars. The Einstein IPC detects 80-85% of the soft X-ray flux emitted by plasma at typical quiescent coronal temperatures for M dwarfs (log T ~ 6.6: Swank and Johnson 1982; Haisch and Simon 1982). Flux variations must therefore be comparable to $L_x$(total) to be detected above the quiescent background; it is such relatively energetic events that influence Einstein or EXOSAT light curves. Thus, it is important to realize that the term "microflare" does not (yet) refer to the same part of the flare energy - frequency relation in the stellar as in the solar context.

X-ray fluctuations on minute to hour timescales (comparable to the timescales suggested by the Einstein light curves) are seen on the Sun, though generally in somewhat harder bandpasses and consequently at much lower flux levels ($10^{23}$-$10^{24}$ ergs $s^{-1}$). The full disk GOES light curves provide many examples (Donnelly and

Bouwer 1981). There is increasing evidence that rapid low level X-ray variability on the Sun is associated with the emergence of magnetic flux through the photosphere. This is seen both in broadband (Mosher 1979) and spectral line studies (Withbroe, Habbal and Ronan 1985). On dKE and dMe stars, the frequent emergence of significant amounts of magnetic flux seems fairly certain, since activity levels are much higher than on the Sun, magnetic fields are much stronger (2500-3800 gauss), and filling factors much larger (~70%: Saar, Linsky and Becker 1985; Saar and Linsky 1985). Thus low level fluctuations associated with flux emergence could conceivably play a much greater role in coronal heating on K and M dwarfs than on the Sun (for which, however, the coronal heating mechanism is still being disputed.) Whether analogous low level fluctuations or microflares occur on dwarf K and M stars and, if so, whether they occur frequently enough and with enough energy to power quiescent stellar coronae must await far more refined observations.

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